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WIND-TUNNEL INVESTIGATION OF THE OPENING CHARACTERISTICS, DRAG,
AND STABILITY OF SEVERAL HEMISPHERICAL PARACHUTES

By

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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION OF THE OPENING CHARACTERISTICS, DRAG,
AND STABILITY OF SEVERAL HEMISPHERICAL PARACHUTES

By Stanley H. Scher and Lawrence J. Gale

SUMMARY

An investigation has been conducted to determine the opening characteristics of several hemispherical parachutes at airspeeds up to 200 miles per hour and to study the influence of the parachute design variables on these opening characteristics. The effects of design variables on the drag and stability characteristics of the parachutes were also evaluated. The tests were made in the Langley 20-foot free-spinning tunnel and in the Langley 300 MPH 7- by 10-foot tunnel.

Some of the parachutes blossomed fully when opened in the air stream. Beneficial effects on the parachute opening characteristics were obtained when longer shroud lines relative to parachute diameter were used, when the floating hem lines were tacked to prevent the hem-line loops from pulling out under load, or when a strip of low-porosity fabric was provided around the canopy in the area immediately above the hem line. The drag characteristics of the parachutes were not appreciably affected by these changes in design. The stability characteristics of the parachutes were affected somewhat adversely by the use of the low-porosity fabric just above the hem line. It was indicated that, for a given parachute, increased airspeeds impaired opening characteristics, lowered drag coefficients, and improved stability.

INTRODUCTION

During a recent investigation of the effects of the stability of tail parachutes opened on airplane models in gliding flight and in spins (reference 1), it appeared desirable that stable parachutes be used as emergency spin-recovery devices. It was felt, however, that when being used as a spin-recovery device the parachute should blossom fully immediately upon being opened so that a maximum drag would be obtained to effect rapid recovery. Brief tests made in connection with reference 1 to determine the opening characteristics of a hemispherical-type parachute, designated Baseball parachute by the manufacturer, General Textile Mills, Inc., indicated that at 200 miles per hour the particular parachute tested might be unsatisfactory as a spin-recovery device because it did not blossom fully immediately upon being opened.

The present tests were made with six additional types of Baseball parachutes, furnished the NACA by General Textile Mills, Inc., to supply more information regarding the principal design variables that influence their opening characteristics. Some of these parachutes were constructed with low-porosity material in the canopy area just above the hem line, a feature which, it had been indicated in reference 1, would affect opening characteristics favorably. Each of the hemispherical parachutes differed somewhat in design and an attempt was made to evaluate generally the effects of shroud-line length, fabric porosity and weight, and hem-line construction upon opening characteristics. Tests were also made to determine the effects of some of these design variables on the drag and stability characteristics of the hemispherical parachutes.

Motion pictures of the opening characteristics of the parachutes were obtained during the tests and are available for loan upon request from NACA Headquarters, Washington, D. C.

SYMBOLS

L	length of parachute shroud lines, feet
D	projected hemispherical diameter of parachute, feet
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
V	airspeed, feet per second
ρ	density of air, slugs per cubic foot
S	projected area of parachute, square feet $\left(\frac{\pi D^2}{4}\right)$
C_D	drag coefficient of parachute $\left(\frac{\text{Drag}}{qS}\right)$

APPARATUS

Wind Tunnels

Tests to determine the opening characteristics of the various hemispherical parachutes were made in the Langley 300 MPH 7- by 10-foot tunnel, which is an atmospheric horizontal wind tunnel. Tests to determine the drag and stability characteristics of the parachutes were made both in the Langley 300 MPH 7- by 10-foot tunnel and in the Langley 20-foot free-spinning tunnel. The Langley 20-foot free-spinning tunnel is a vertical atmospheric wind tunnel with a vertically rising air stream.

Parachutes

The parachutes used in this investigation, Baseball parachutes, have preformed hemispherical canopy shapes. The construction and dimensions of the parachutes as well as the porosity and weight of the canopy fabrics are shown in figures 1 to 7. The letter and numbers used in designating each parachute were the manufacturer's model designation. The porosities given for the material in the parachutes were obtained from the manufacturer and are presented as the cubic feet of air that will pass through 1 square foot of the cloth per minute under a pressure of 1/2 inch of water. The weight nylon presented on the figures indicates the approximate weight of 1 square yard of the cloth. The parachutes were constructed with floating hem lines (fig. 8), as is customary in manufacturing Baseball type parachutes. During many of the tests, the hem lines were tacked (fig. 9) to prevent the hem-line loops from pulling out and thus distorting the parachute shape during opening.

METHODS AND TESTS

For testing the opening characteristics of the parachutes in the Langley 300 MPH 7- by 10-foot tunnel, the packed parachute with its towline was fastened to a cable which in turn was fastened to the tunnel balance scale. When an airspeed of about 200 miles per hour was attained, the pack was opened from outside the tunnel by pulling a chord attached to a pin which held a canvas restraining wrapper on the parachute pack. The ensuing action of the parachute was then observed and motion pictures were made of the tests. A pictorial sketch of an open parachute in the Langley 300 MPH 7- by 10-foot tunnel is presented in figure 10.

For the parachutes which blossomed fully when opened in the Langley 300 MPH 7- by 10-foot tunnel, drag-force measurements were made for an airspeed of 200 miles per hour. In the Langley 20-foot free-spinning tunnel, the drag of the parachute was determined from free tests during which the fully blossomed parachute supported a small spherical weight in the vertically rising air stream. The drag of the parachute was then taken to be equal to the sum of the weight of the parachute and the suspended weight. The drag coefficients calculated were based on the projected area of the hemispherical canopies. The tunnel airspeed during these tests was approximately 17 miles per hour.

The stability of each parachute which blossomed fully at 200 miles per hour in the Langley 300 MPH 7- by 10-foot tunnel was determined by observing its behavior at this speed. Also, the stability of each parachute was determined at a speed range of 30 to 46 miles per hour for the fully blossomed parachutes which were fastened to a horizontal bar in the Langley 20-foot free-spinning tunnel. At a given airspeed, parachutes which aligned themselves with the air stream or which inclined

no more than a few degrees (3 or 4) from the air stream and did not oscillate were considered stable.

RESULTS AND DISCUSSION

The results of the investigation to determine the opening and stability characteristics of the parachutes are presented in table I. All parachutes which blossomed fully or even opened to a pear shape withstood the force of the air at 200 miles per hour without tearing. The results of drag measurements are shown in figure 11.

Parachute Opening Characteristics

Effect of shroud-line length.— Parachute D-358 did not blossom to a hemispherical shape when the pack was opened at 208 miles per hour, but rather opened to a pear shape (this result repeated from reference 1). Parachutes D-389 and D-391 did not open as fully as did parachute D-358. Inasmuch as parachutes D-389 and D-391 had been especially constructed with low-porosity fabric in the canopy area just above the hem line, a feature which, it had been indicated in reference 1 would be favorable for good opening characteristics, it appears that the poorer opening characteristics of parachutes D-389 and D-391 were caused by their lower shroud-line length to parachute diameter ratio (one as compared to three for parachute D-358). This result is in agreement with reference 2, wherein long shroud-line length relative to parachute diameter is recommended for good opening characteristics of parachutes. Film strips showing the opening of parachutes D-358 and D-389 are presented in figure 12.

Effect of hem-line tacking.— Baseball parachutes, as previously indicated, are generally constructed with a floating hem line, the operation of which is shown in figure 8, and parachutes D-358, D-389, and D-391 all had this type of hem line when tested. In an attempt to obtain satisfactory opening characteristics at 200 miles per hour of parachutes D-389 and D-391, the hem lines of these parachutes were tacked in such a manner as to prevent the hem-line loops from pulling out appreciably. (See fig. 9.) With the hem line tacked, the parachutes blossomed fully at 200 miles per hour except for a slight contraction caused by the shroud lines pulling out small loops of the hem chord. Film strips showing the opening of parachute D-389 with its hem line tacked are presented in figure 13. It is believed that had the hem line been tacked completely the slight contraction of the parachute would not have occurred. Because tacked hem lines had such a beneficial effect on the opening characteristics of parachutes D-389 and D-391, all the parachutes subsequently tested were tested only with tacked hem lines.

Effect of fabric porosity.— Parachute D-393 (fig. 5) did not open in the air stream at an airspeed of 200 miles per hour. As the airspeed was reduced, it tended to open a little but still did not open fully. The failure of this parachute to open was probably due to the fact that the entire canopy was constructed of high-porosity fabric (502), and the result obtained is in general agreement with the results of reference 1. The fact that parachute opening characteristics are affected adversely as porosity is increased is also pointed out in reference 2. Parachute D-390 (fig. 6) also did not open in the air stream at 200 miles per hour. Parachute D-390 was generally similar in construction to parachutes, D-389, D-391, and D-392, but the fabric porosity in the region just above its hem line was higher (162 as compared to 96, 137, and 118, respectively). It thus appears that the failure of parachutes D-390 and D-393 to open in the air stream may be a further substantiation that a region of low-porosity fabric immediately above the tacked hem line of a parachute has a favorable effect on its opening characteristics.

Effect of fabric weight.— There appeared to be little effect of the weight of the fabric upon the opening characteristics of the parachutes.

Effect of crown vent.— Parachute D-394 differed from the other parachutes tested primarily in that it had a single-thickness low-porosity crown with a high-porosity vent. The parachute opened to a pear shape at 200 miles per hour in a manner similar to parachute D-358. As the speed was lowered, it opened more than at high speeds but it still did not open fully. Comparison of the construction of parachute D-394 (fig. 7) with that of D-358 (fig. 1) indicates that in addition to differences in crown construction, parachute D-394 differed from D-358 in that it had lower porosity in the main body of its canopy, had a tacked hem line, and had a lower ratio of shroud-line length to parachute diameter. The first two differences should have been beneficial to opening characteristics of parachute D-394, whereas the third should have impaired its opening characteristics. Inasmuch as the quantitative effects of the aforementioned design differences were not known, it was not possible to evaluate the effect of the differences in the crown nor the effect of the vent. A comparison of parachute D-394 with parachute D-389 indicates that, in addition to differences in crown construction, parachute D-389 had a region of low-porosity fabric immediately above the hem line. The results indicate that alteration of the crown construction, including the addition of the vent, did not tend to improve opening characteristics as much as the installation of the low-porosity fabric immediately above the hem line.

Effect of Design Variables on Parachute Drag Characteristics

The drag coefficients obtained for each parachute tested in the Langley 20-foot free-spinning tunnel (at approximately 17 mph) are plotted

as a function of the porosity of the fabric of the large middle panel of the parachute canopy (fig. 11). The test points fall in the region of the porosity-drag coefficient curve in reference 1 (redrawn on fig. 11); in reference 1 each Baseball parachute had its entire canopy made of material of a given porosity. The results indicate that the parachute design variables investigated did not appreciably affect the drag characteristics of Baseball type parachutes.

Drag coefficients obtained for the parachutes in the Langley 300 MPH 7- by 10-foot tunnel (at approximately 200 mph) are also plotted on figure 11. All of these drag coefficients are appreciably lower than those obtained at low speeds in the free-spinning tunnel. The decrease in drag coefficients may have been in part due to distortion or changes in the parachute fabric with the increase in airspeed which may have resulted in greater porosity. This result is in general agreement with reference 1, wherein it is indicated that when a Baseball parachute was opened at low speed, the drag coefficients decreased as the speed was increased to 200 miles per hour even though the parachute remained fully blossomed. In addition to fabric distortion, the slight contraction of the parachutes when opened at 200 miles per hour (table I) may have been a factor contributing toward the decrease in drag coefficients.

Effect of Design Variables on Parachute Stability Characteristics

The results of the investigations made to determine the stability of the parachutes are presented, as mentioned previously, in table I. Only parachutes D-358 (porosity 400) and D-393 (porosity 502) were stable at all airspeeds tested. The results obtained with these two parachutes are in agreement with results presented in reference 1 which indicate that the stability of a parachute improves as the porosity increases, and that for porosities over 400 the angle a parachute makes with the air stream approaches zero.

Although not specifically determined during the present investigation, it has been indicated in references 1 and 2 that shroud-line length has little effect on the stability of a parachute. Since parachutes D-389, D-390, D-391, D-392, and D-394 were not stable at 30 to 46 miles per hour, it appears that the use of low-porosity fabric near the hem line impaired the stability characteristics of the parachutes somewhat for these speeds. At 200 miles per hour no appreciable adverse effect of low-porosity fabric near the hem line was indicated. A general comparison of the stability indicated for the parachutes at 200 miles per hour and at 30 to 46 miles per hour indicated greater stability for a given parachute at the higher airspeed. As previously discussed, possible distortion in the parachute fabric at high speed may have effectively increased the porosity; this may explain the increase in stability.

As shown in table I, parachute D-392 was somewhat less stable at all airspeeds tested than were parachutes D-389 and D-391. This may be a

result of the appreciably greater weight of the fabric in parachute D-392 as compared with the fabric used in the other two parachutes. Based on this single test result, it appears that fabric weight may be a secondary factor contributing to parachute stability.

It should be possible to develop a hemispherical or other type of parachute that will blossom fully and quickly and yet be stable, such as is desirable for spin-recovery parachutes, by application of the principles and results discussed herein and in reference 1. These results indicate that as airspeed is increased, the opening and drag characteristics of a given parachute are affected adversely, whereas the stability characteristics are improved. Proposed parachute designs should be checked by testing of the full-scale parachutes at the desired airspeeds before being selected for a specific use.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of tests of several hemispherical parachutes to study their opening characteristics and to evaluate the effects of the parachute design variables on the opening, drag, and stability characteristics of the parachutes, the following conclusions and recommendations are made:

1. Some of the parachutes blossomed fully in the air stream if their hem lines were tacked.
2. In general, beneficial effects on hemispherical-parachute opening characteristics were obtained when greater shroud-line length as compared with parachute diameter was used, when the floating hem lines were tacked to prevent the hem-line loops from pulling out under load, or when a strip of low-porosity fabric was provided around the canopy in the area immediately above the hem line.
3. The drag characteristics of the parachutes were not appreciably affected by changes in shroud-line length, by tacking of hem lines, or by use of a low-porosity fabric strip above the hem line.
4. The stability characteristics of the parachutes were affected somewhat adversely by the use of the low-porosity fabric just above the hem line.
5. For a given parachute, increased airspeeds generally impaired opening characteristics, decreased the drag coefficient, and improved the stability.

6. Proposed parachute designs should be checked by testing of full-scale parachutes at the desired airspeeds before being selected for a specific use.

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1. Scher, Stanley H., and Draper, John W.: The Effects of Stability of Spin-Recovery Tail Parachutes on the Behavior of Airplanes in Gliding Flight and in Spins. NACA RM No. L8E19, 1948. *conf.*
2. Johns, T. F.: Parachute Design. TN No. Arm. 365, British R.A.E., Dec. 1946.

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TABLE I

OPENING AND STABILITY CHARACTERISTICS OF VARIOUS HEMISPHERICAL PARACHUTES DETERMINED FROM TESTS IN

THE LANGLEY 300 MPH 7- BY 10-FOOT TUNNEL AND THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL

[Unless otherwise indicated all parachutes were 30-in. in diameter, had 16 shroud lines, had ratio of shroud-line length to parachute diameter of 1, had tacked hem lines, and had double-thickness crown]

Parachute					Opening characteristics		Stability characteristics		
Designation	Porosity (cu ft/sq ft/min at 1/2 inch of water)		Weight of nylon (oz/sq yd)		Description of test	Behavior of parachute	At 200 mph	At 30 to 46 mph	
	Fabric immediately above hem line	Fabric in main panel and in crown	Fabric immediately above hem line	Fabric in main panel and in crown				Maximum angle parachute made with air stream (deg)	Comments
a,b,c D-358	400	400	1.5 to 2.0 (estimated)	1.5 to 2.0 (estimated)	Parachute pack opened at tunnel airspeed of 208 mph	Parachute opened and assumed pear shape	-----	4	Parachute was very steady in air stream
					Tunnel airspeed reduced from 208 mph to 0	Parachute retained pear shape as speed was reduced	-----	-----	-----
c D-389	96	362	1.38	1.49	Parachute pack opened at tunnel airspeed of 200 mph	Parachute opened only partially; whipping action caused para- chute to start tearing	-----	-----	-----
					Airspeed reduced	Parachute tended to open a little	-----	-----	-----
					Parachute forced open by hand at low air- speed, then air- speed increased gradually to 200 mph	Parachute remained open as airspeed was increased until at 200 mph para- chute suddenly collapsed again to partially open condition	-----	-----	-----
c D-391	137	404	2.18	4.81	Parachute pack opened at tunnel airspeed of 200 mph	Results similar to those for parachute D-389	-----	-----	-----
D-389 and D-391	96	362	1.38	1.49	Parachute pack opened at tunnel airspeed of 200 mph	Parachutes blossomed fully except for slight reduction in diameter caused by shroud lines pulling out small loops of the hem chord	Parachutes were fairly steady with slight tendency to rotate	D-389-10 D-391-8	Parachute D-389 tended to circle around somewhat and occasionally made angle of 0° with air stream
	137	404	2.18	4.81					

^aParachute 11.84-in. in diameter.

^bRatio of shroud-line length to parachute diameter, 3.

^cHem line not tacked.

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TABLE I
OPENING AND STABILITY CHARACTERISTICS OF VARIOUS HEMISPHERICAL PARACHUTES DETERMINED FROM TESTS IN
THE LANGLEY 300 MPH 7- BY 10-FOOT TUNNEL AND THE LANGLEY 20-FOOT FREE-SPINNING TUNNEL - Concluded

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Parachute					Opening characteristics		Stability characteristics		
Designation	Porosity (cu ft/sq ft/min at 1/2 inch of water)		Weight of nylon (oz/sq yd)		Description of test	Behavior of parachute	At 200 mph	At 30 to 46 mph	
	Fabric immediately above hem line	Fabric in main panel and in crown	Fabric immediately above hem line	Fabric in main panel and in crown				Maximum angle parachute made with air stream (deg)	Comments
D-391	137	404	2.18	4.81	Hem line of parachute forced completely open, airspeed increased to 200 mph	Parachute contracted slightly as shroud lines pulled out small loops of the hem chord	-----	--	-----
D-392	118	438	7.94	6.15	Parachute pack opened at tunnel airspeed of 200 mph	Parachute blossomed same as D-389 and D-391 with tacked hem line	Parachute floated at small angle with air stream and was not as steady as parachutes D-389 and D-391 with tacked hem lines	11	Parachute tended to move back and forth and occasionally made angle of 0° with air stream
D-393	502	502	4.5	4.5	Parachute pack opened at tunnel airspeed of 200 mph	Parachute did not open; whipping action caused parachute to start tearing	-----	0	Parachute was very steady in air stream
					Airspeed reduced	Parachute tended to open a little	-----	--	-----
D-390	162	407	2.24	2.14	Parachute pack opened at tunnel airspeed of 200 mph	Parachute did not open	-----	8	-----
					Airspeed reduced	Parachute tended to open in a pear shape	-----	--	-----
dD-394	318	Main panel 318 Crown 137	1.38	Main panel 1.38 Crown 2.3	Parachute pack opened at tunnel airspeed of 200 mph	Parachute opened and assumed pear shape	-----	6	Parachute moved continuously back and forth in air stream
					Airspeed reduced	Parachute opened more fully but was not fully open even at low airspeeds	-----	--	-----
					Airspeed increased	Parachute again became pear shaped	-----	--	-----

^dSingle crown thickness with crown vent of 4.50 oz per sq yd nylon, porosity 502.

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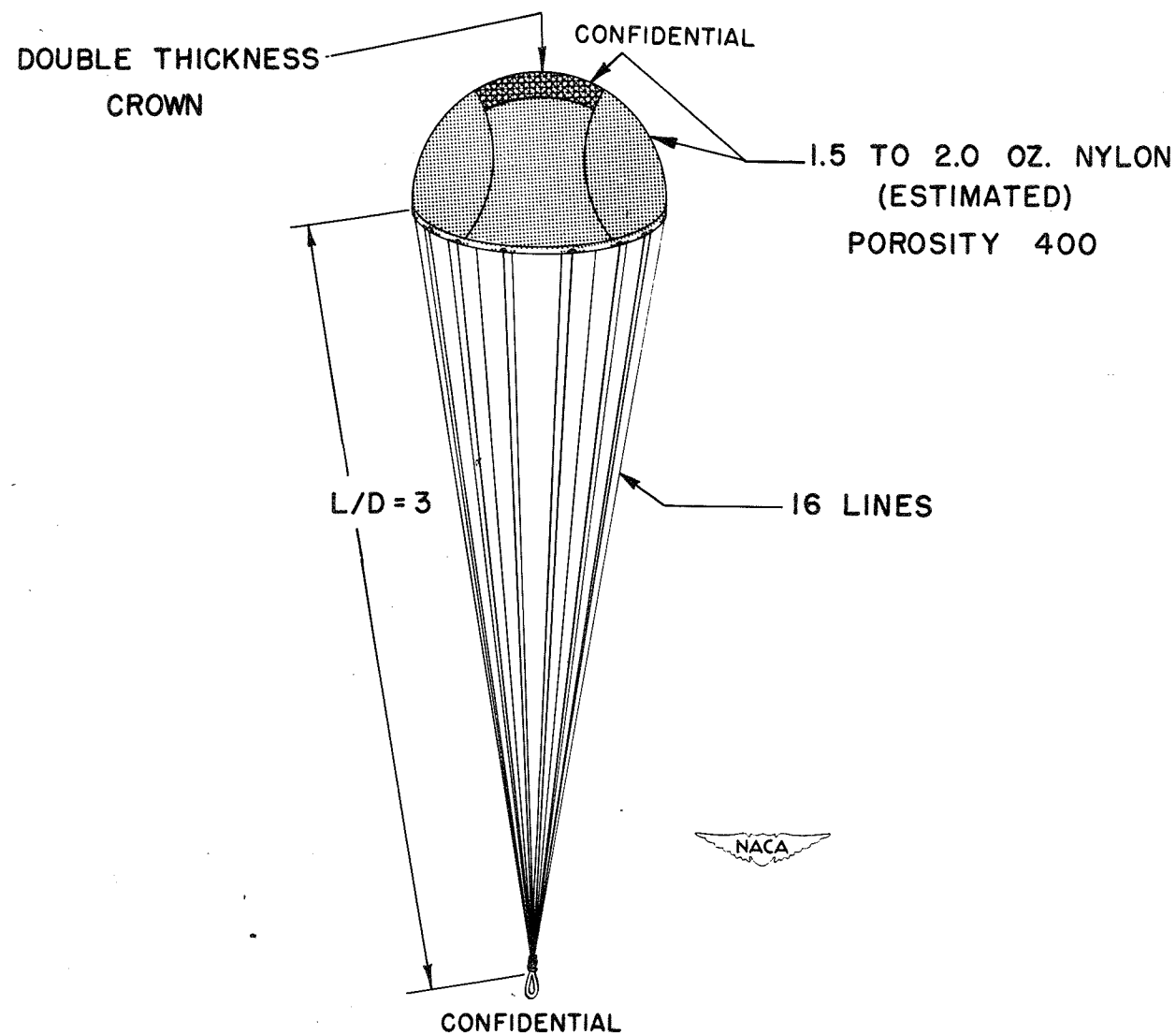


Figure 1.- Type D-358 11.84-inch-diameter parachute.

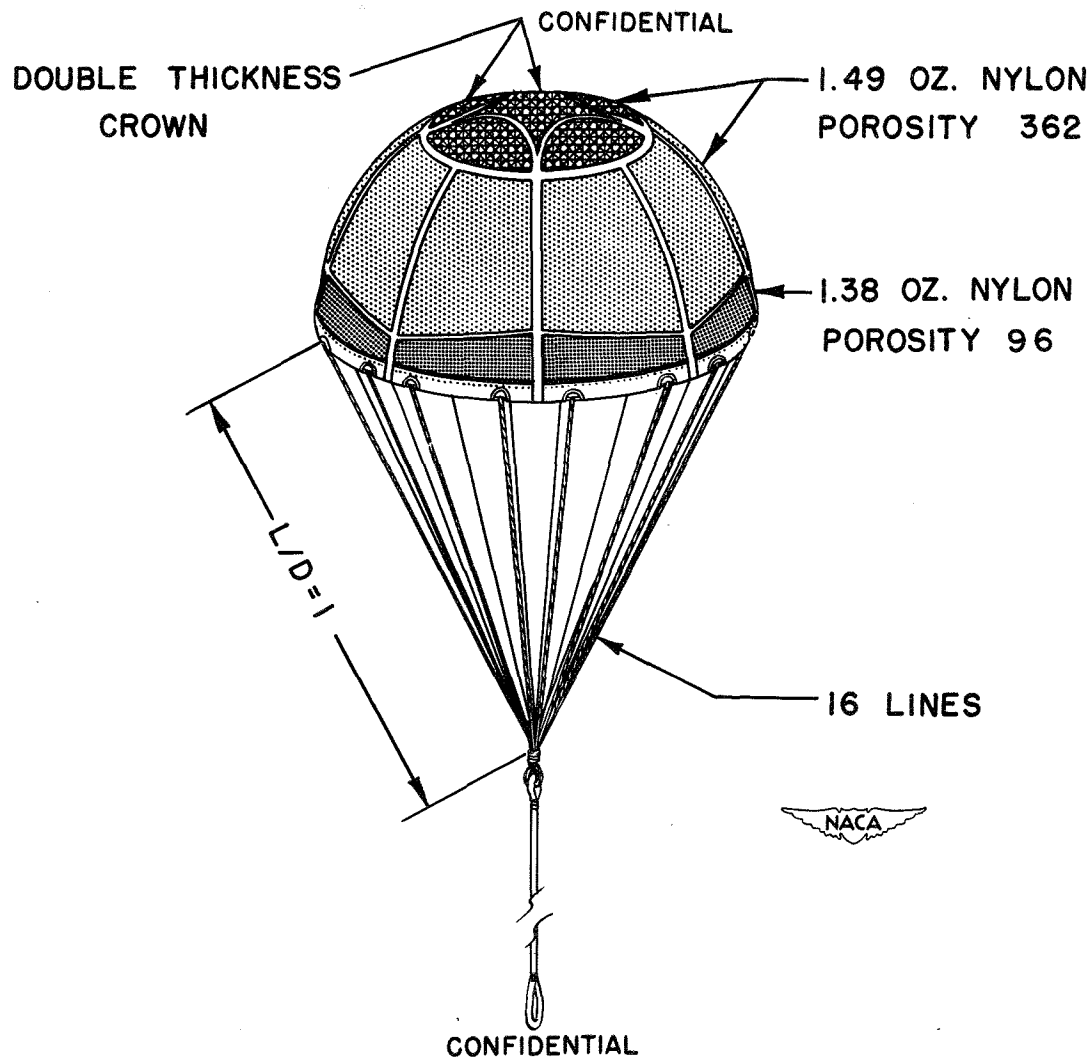


Figure 2.- Type D-389 30-inch-diameter parachute.

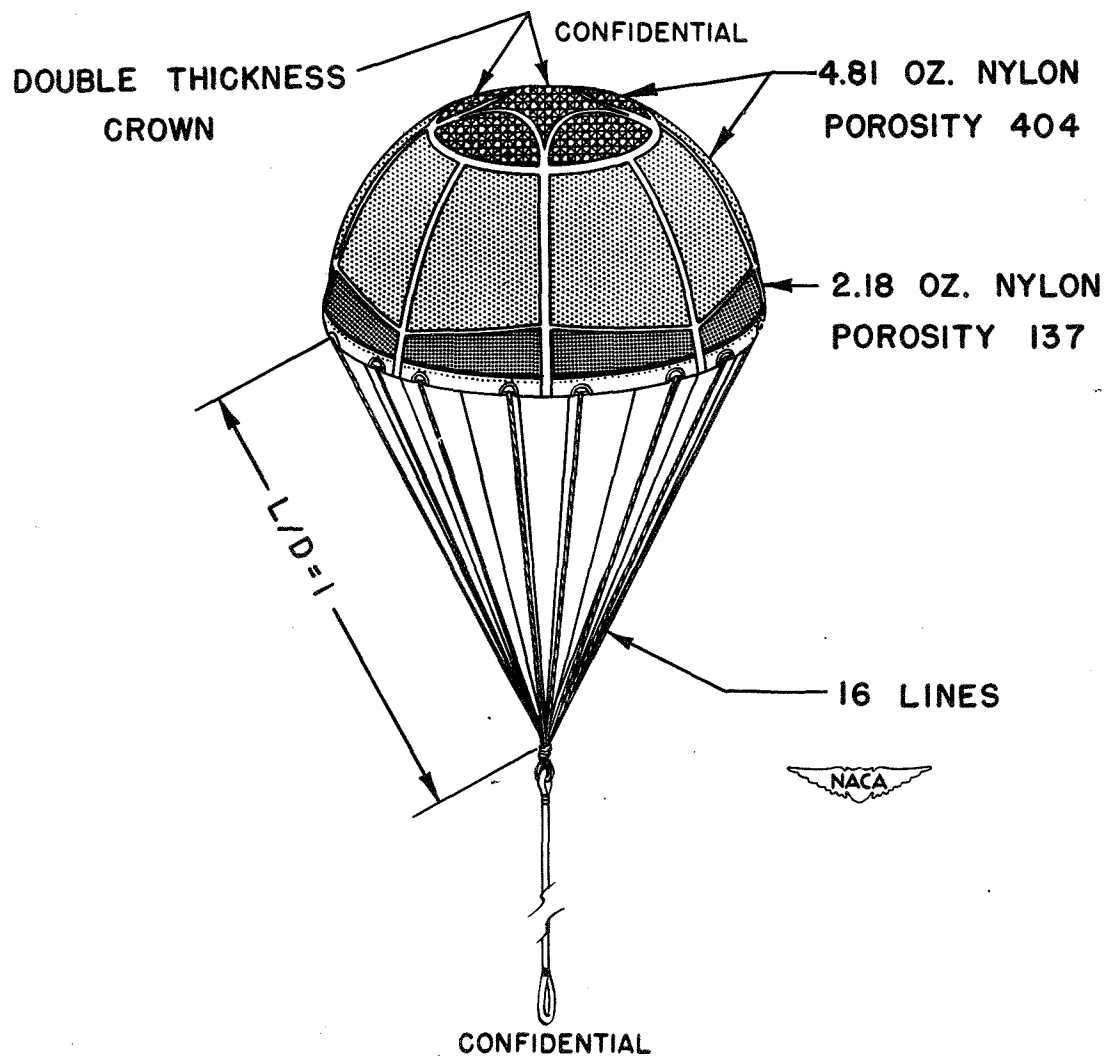


Figure 3.- Type D-391 30-inch-diameter parachute.

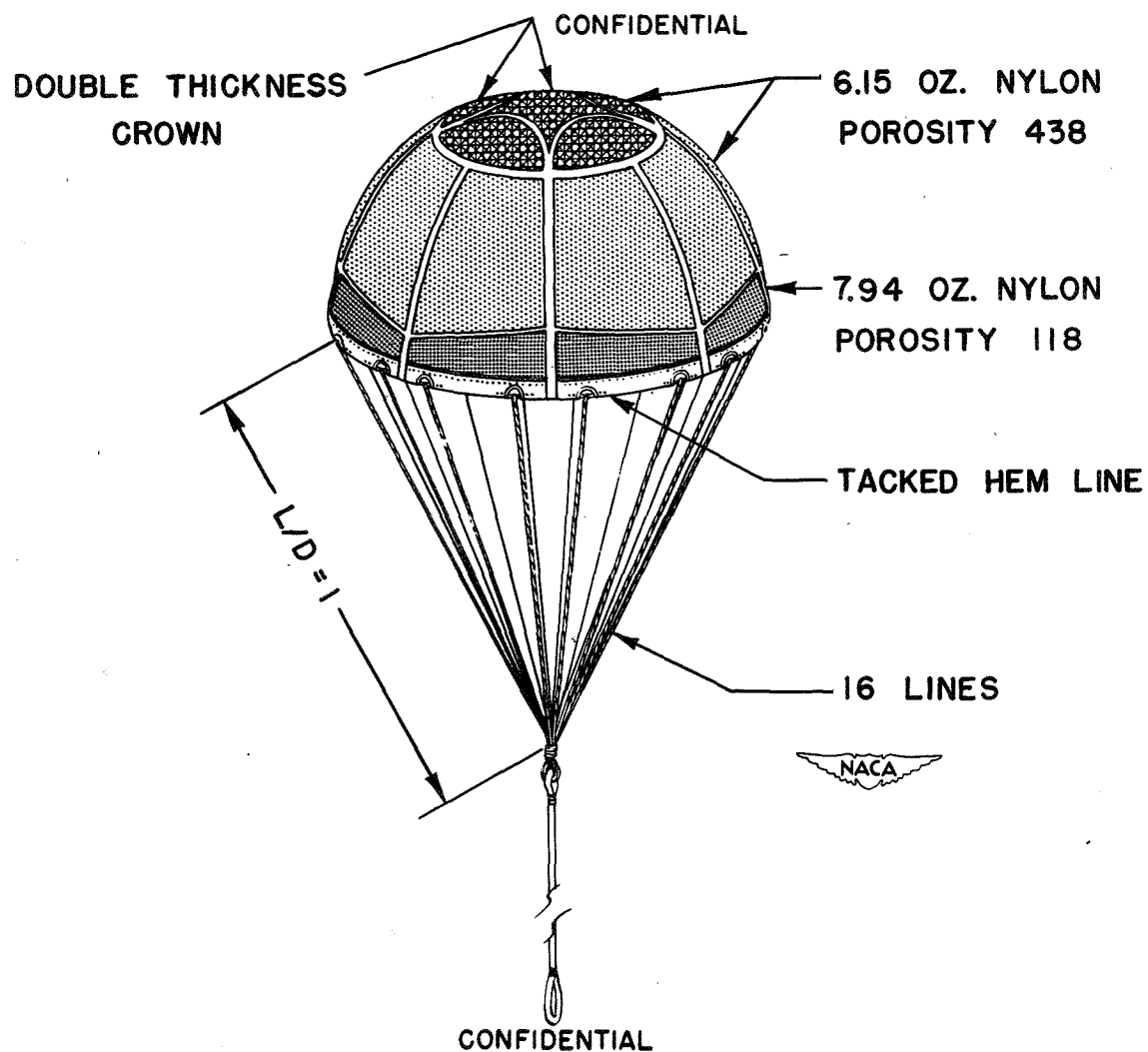


Figure 4.- Type D-392 30-inch-diameter parachute.

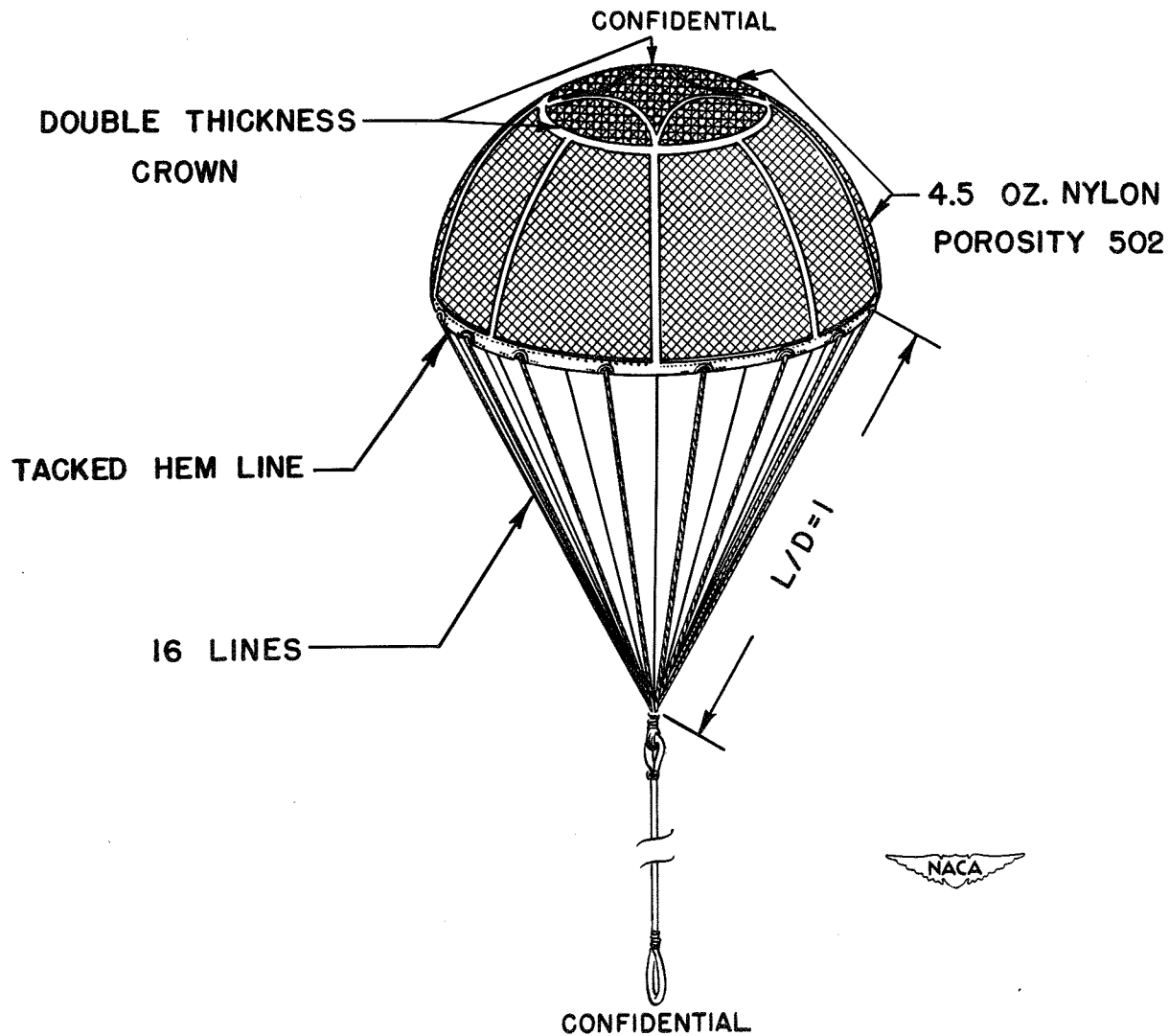


Figure 5.- Type D-393 30-inch-diameter parachute.

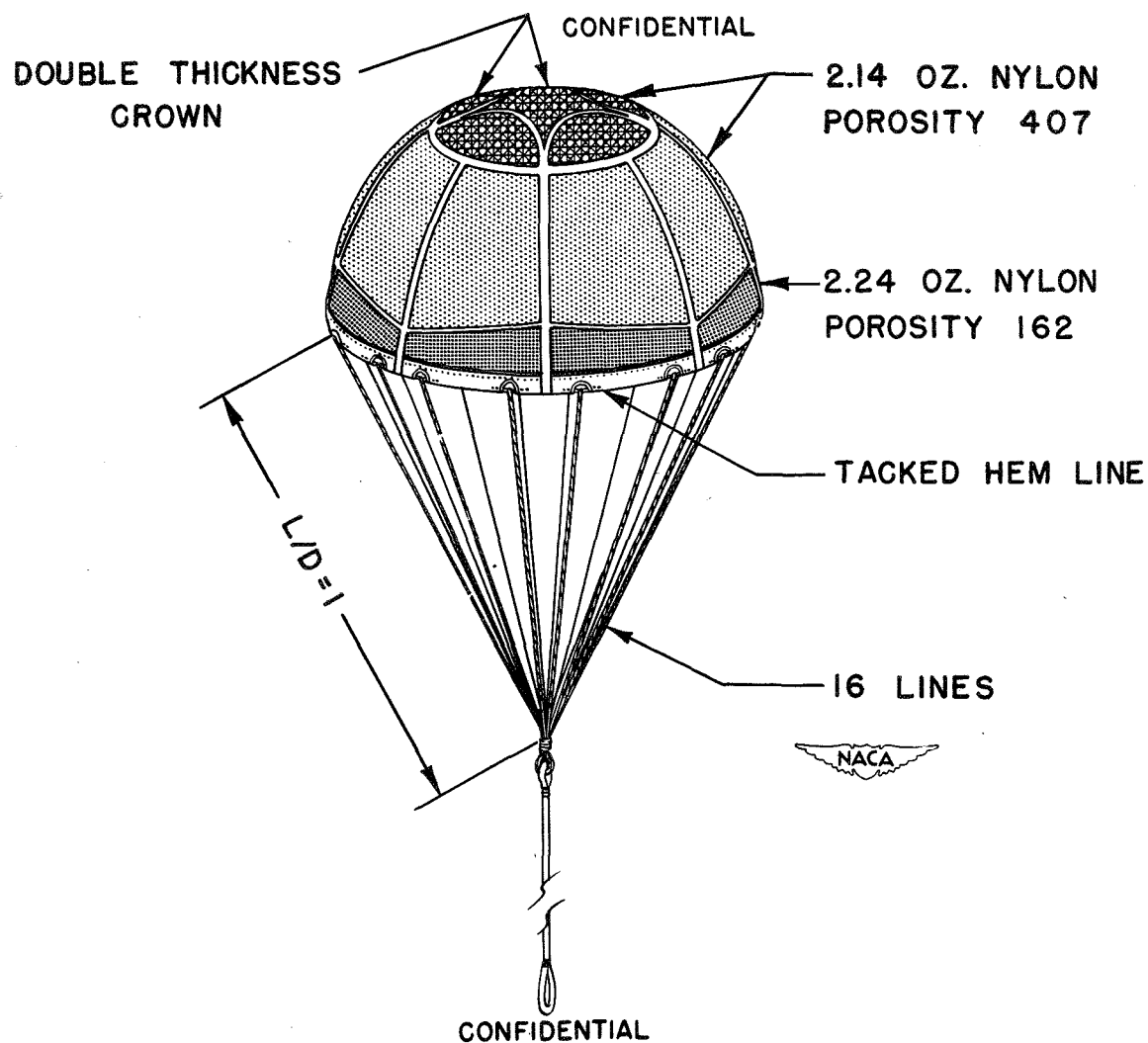


Figure 6.- Type D-390 30-inch-diameter parachute.

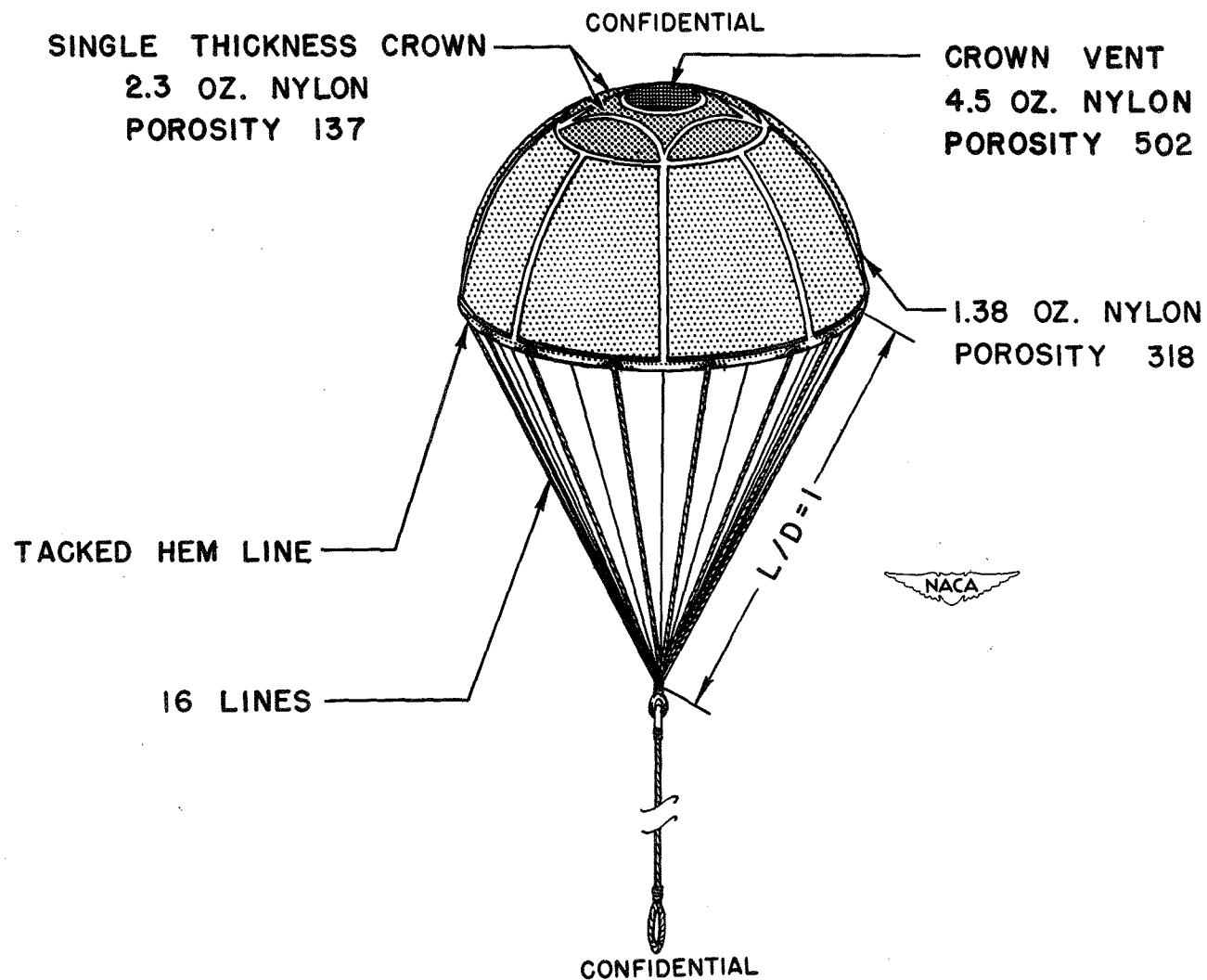


Figure 7.- Type D-394 30-inch-diameter parachute.

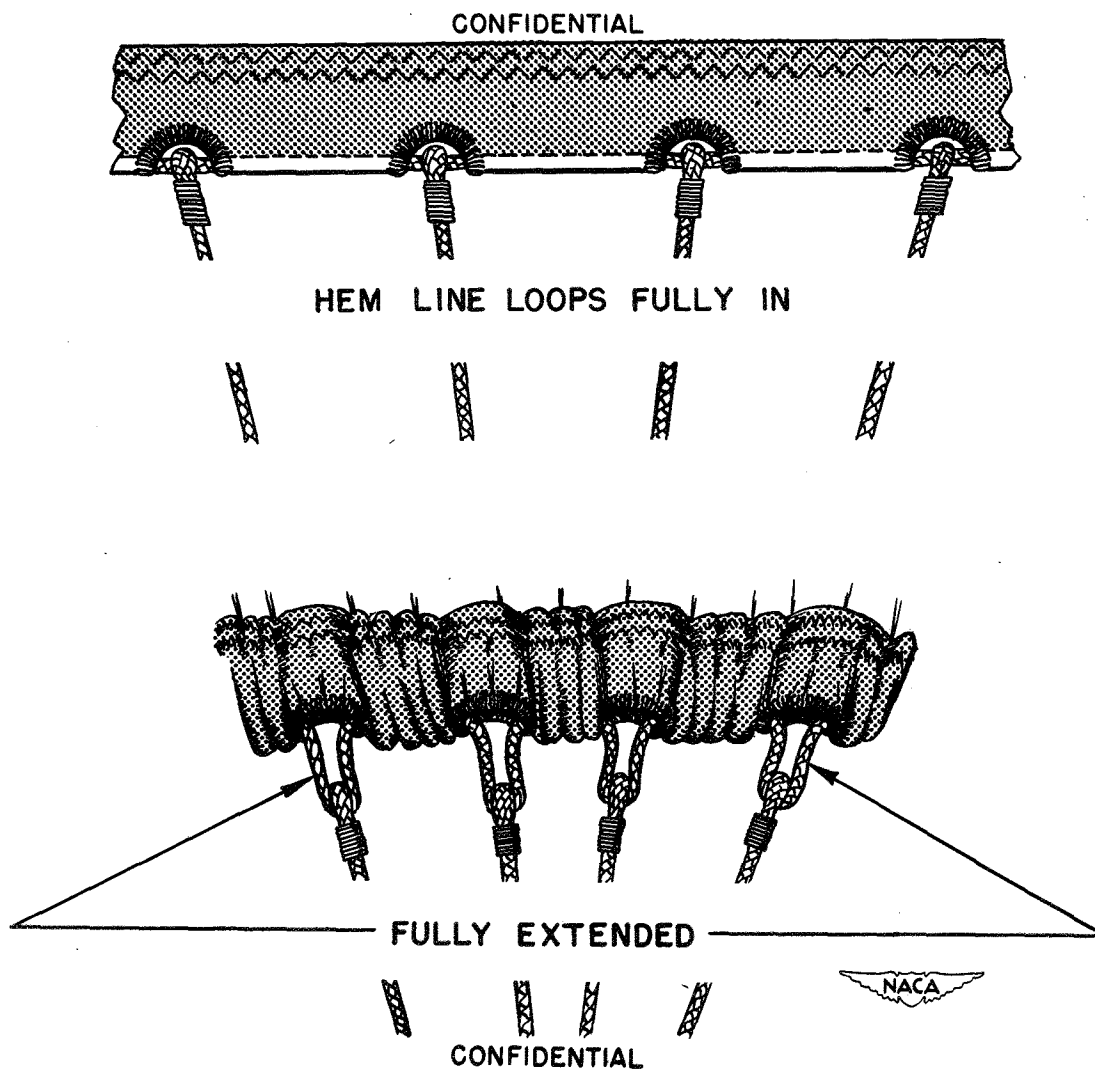
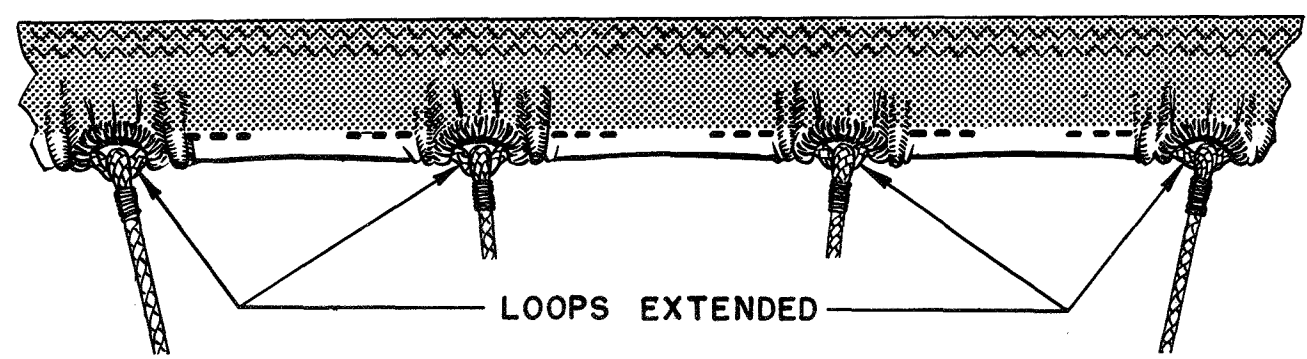
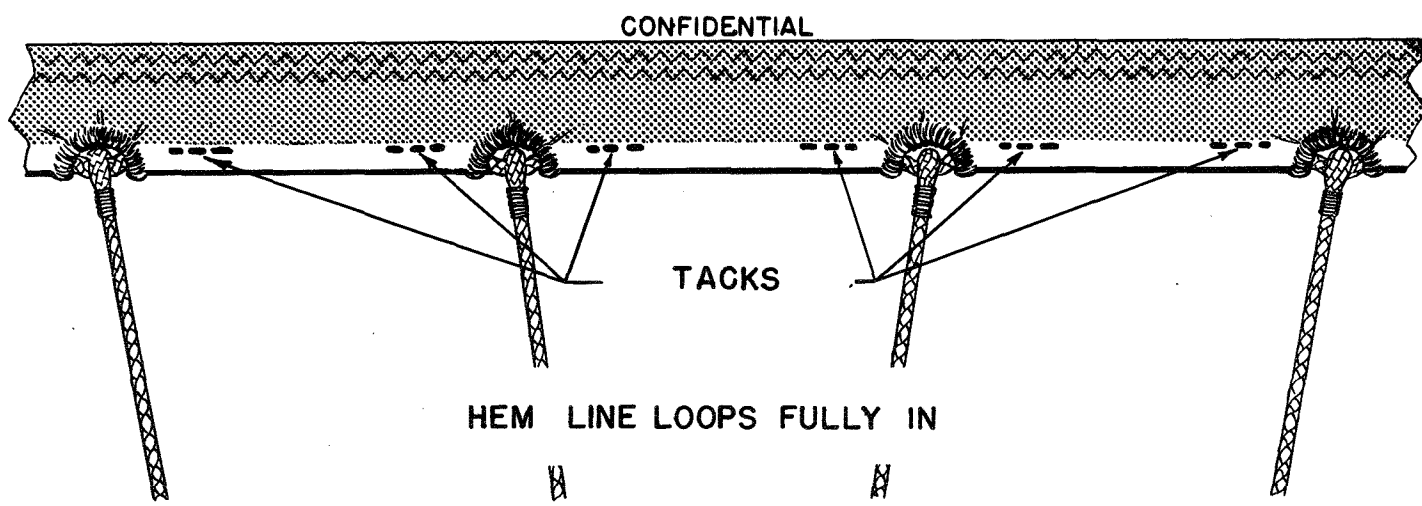


Figure 8.- Floating hem line.

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Figure 9.- Tacked hem line.

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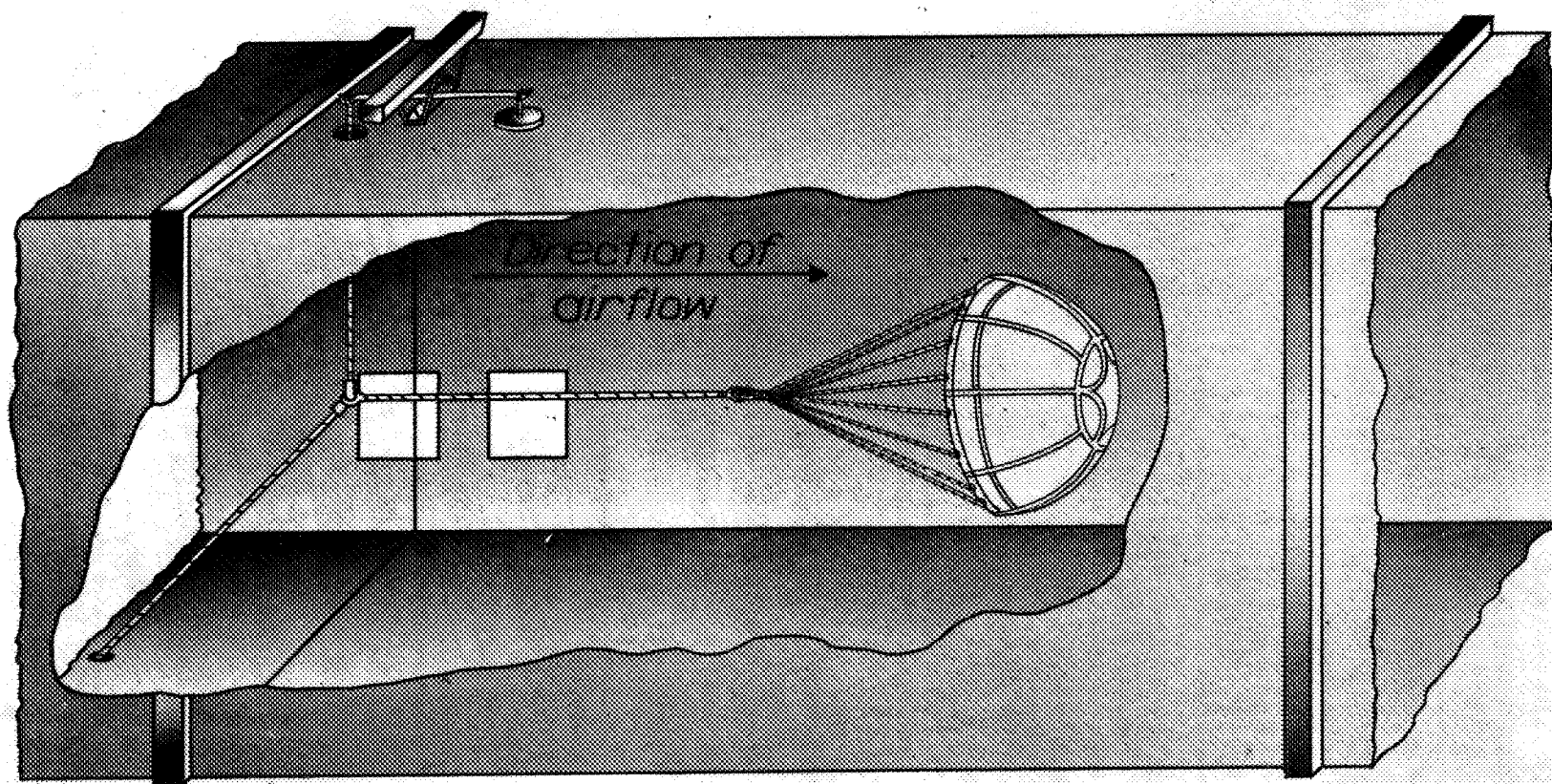


Figure 10.- Pictorial sketch of open Baseball type parachute in Langley 300 MPH 7- by 10-foot tunnel.

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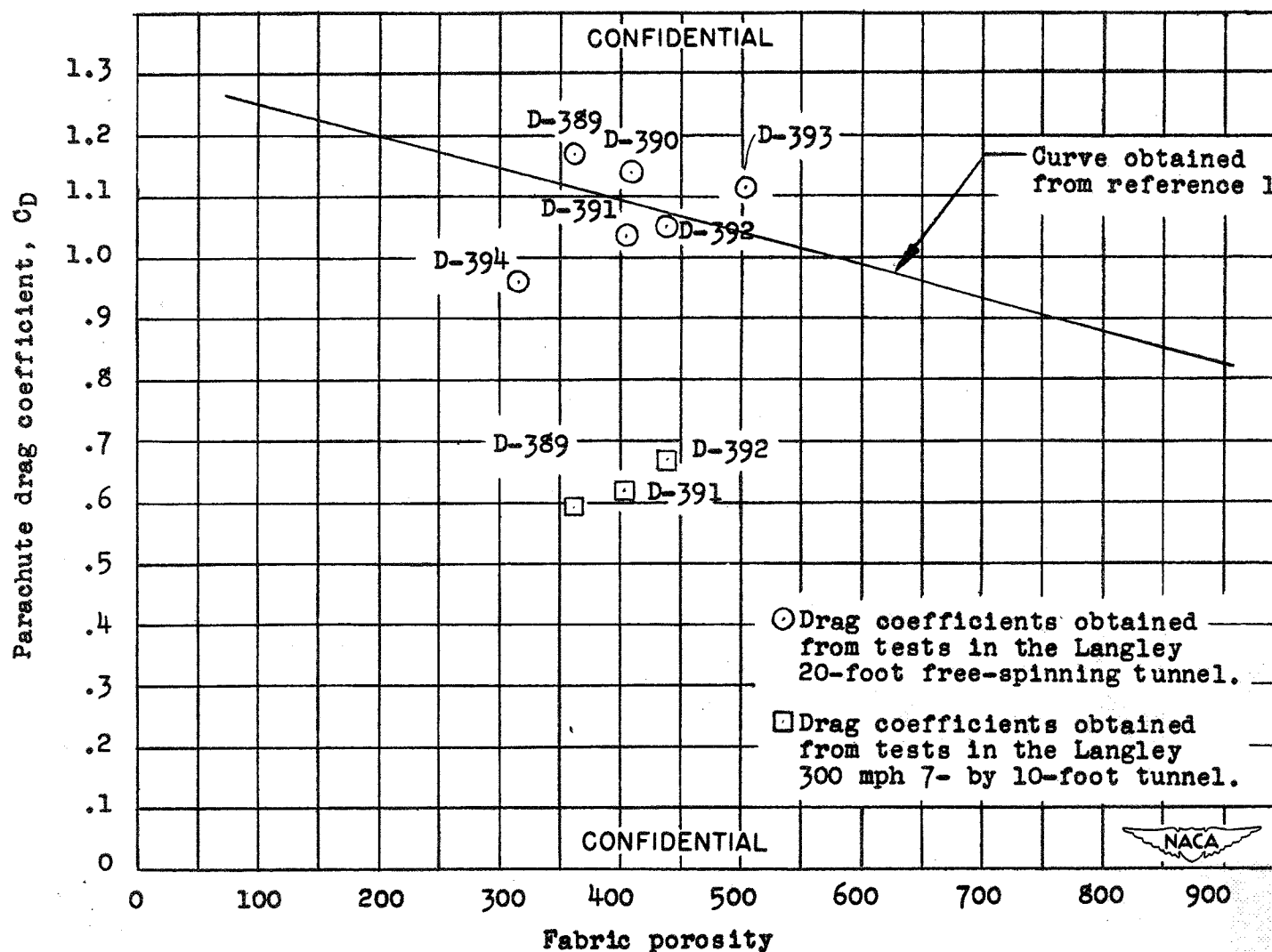
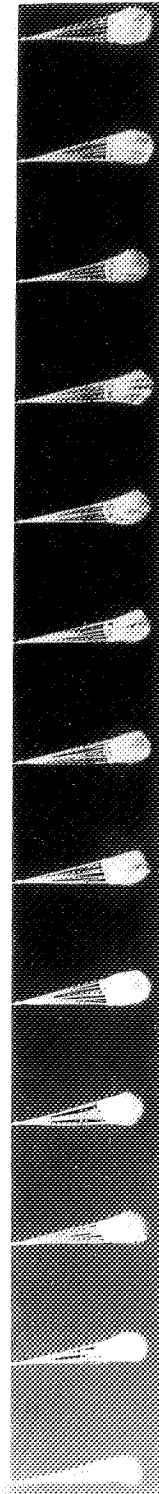
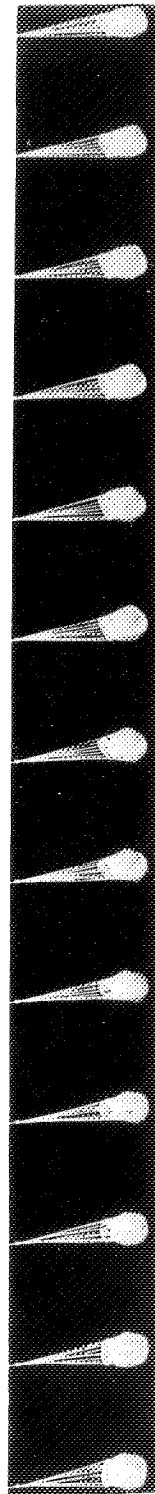
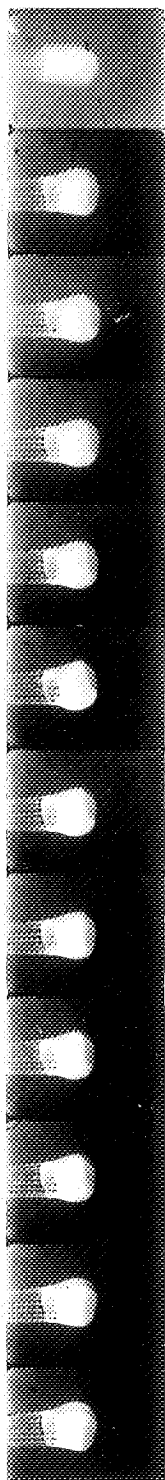


Figure 11.- Variation of parachute-drag coefficient with porosity for Baseball type parachutes tested in the Langley 20-foot free-spinning tunnel and in the Langley 300 MPH 7- by 10-foot tunnel.

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(a) D-358 Tunnel
airspeed, 208 miles per hour.

(b) D-389. Tunnel
airspeed, 200 miles per hour.

Figure 12.- Film strips showing the opening of parachutes D-358 and D-389 in the Langley 300 MPH 7- by 10-foot tunnel. Pictures were made at camera speed of 64 frames per second.

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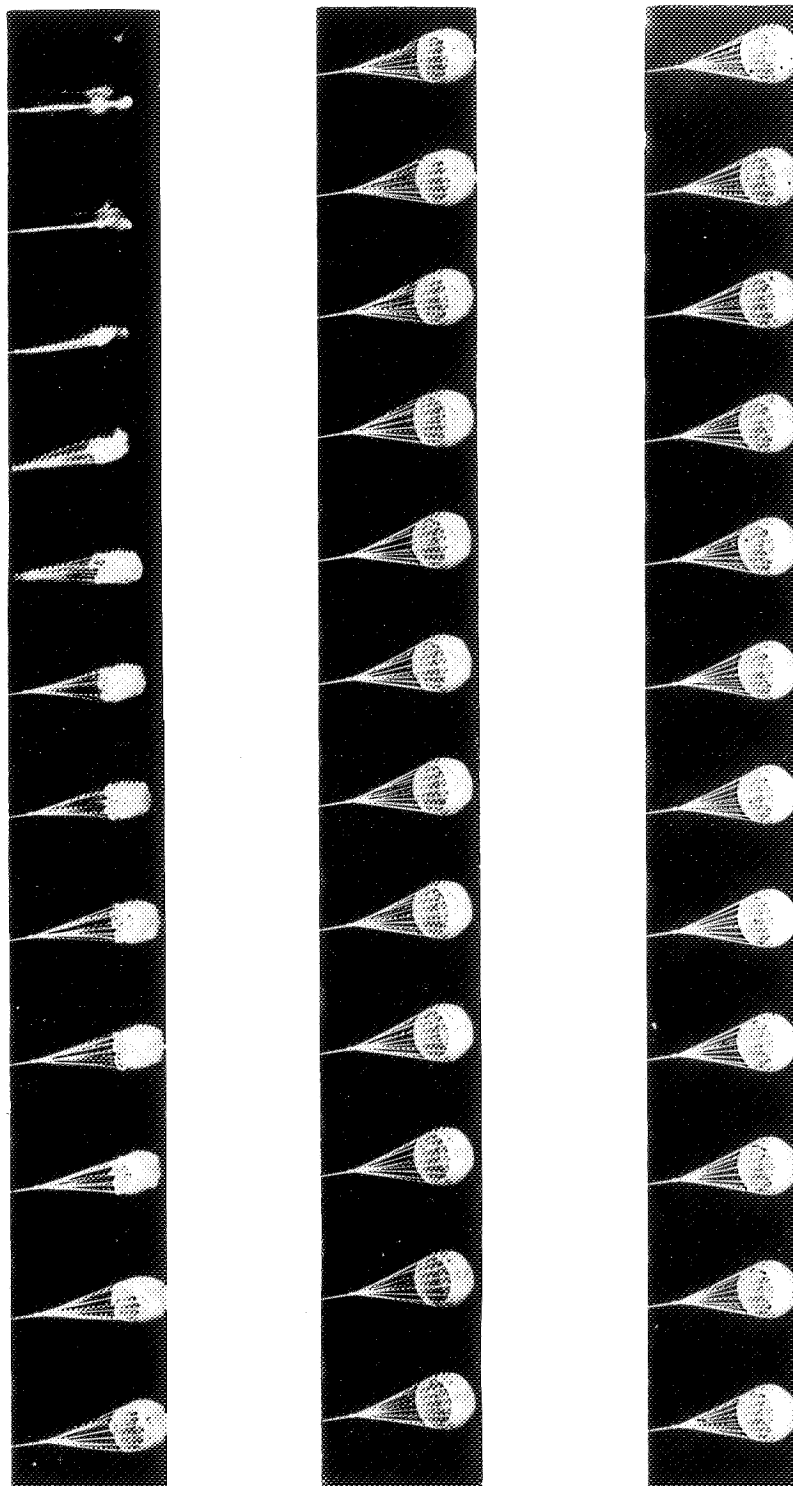


Figure 13.- Film strips showing the opening of parachute D-389 with tacked hem line in the Langley 300 MPH 7- by 10-foot tunnel. Tunnel airspeed, 200 miles per hour. Pictures were made at camera speed of 64 frames per second.

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ABSTRACT

An investigation has been conducted to determine the opening characteristics of several hemispherical parachutes and to study the influence of the parachute design variables on these opening characteristics. The effects of design variables on the drag and stability characteristics of the parachutes were also evaluated. The tests were made in the Langley 20-foot free-spinning tunnel and in the Langley 300 MPH 7-by 10-foot tunnel.